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OPEN BIM IN COURSES IN ENGINEERING EDUCATION

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Abstract

The Technical University of Denmark has included open BIM in its BIM or BIM-related courses for bachelor, master and PhD students studying civil or architectural engineering. A majority of students are introduced to open BIM during their education, and those who are selecting courses in advanced BIM or building design are becoming more familiar with the concept. A number of students are including open BIM in their bachelor projects or master theses. The main reason for including open BIM in teaching is that open BIM has been a mandatory deliverable in Denmark since 2007 in state-financed construction projects through the IFC format. From 2013 the requirements also included social housing and all public building projects.

Students are exploring the capabilities of open BIM, and have been able both to identify satisfactory results as well as propose enhancements in order to compensate for shortcomings in the existing specification or implemented solutions in software products.

1. Introduction

As delivering Building Information Modeling (BIM) models in Industry Foundation Classes (IFC) format [1] became mandatory in state-financed construction projects in Denmark in 2007 [2], the Technical University of Denmark (DTU) has included lectures in open BIM in several of its BIM or BIM-related courses. Civil and architectural engineering students are introduced to open BIM through elements like BIM Collaboration Format (BCF) [3], Information Delivery Manual (IDM) [4], and IFC that are developed by buildingSMART and accepted as ISO standards.

The university has included open BIM in its courses in order for students to be familiar with the concept and to stimulate the exchange of digital model-based information in the construction and facilities management industries. An area which is considered to be of the greatest importance for the integrated cooperation within the construction industry.

2. Methodology

This paper is based on information on the courses that are available for Bachelor of Engineering (BEng) in Building Design, Bachelor of Science (BSc) in Building Design, Bachelor of Science in Civil Engineering, Master of Science (MSc) in Building Design, Master of Science in Civil Engineering and PhD students at the Technical University of Denmark in relation to open BIM. In addition to the ordinary courses, lists of contributions from students in special courses, bachelor projects, master theses and PhD projects are included.

The presented experiences are generated from the findings gathered by the author in assisting or correcting exercises, projects and master theses.

3. Curriculum in BIM and open BIM

DTU is offering a number of courses in BIM and open BIM for BEng, BSc, MSc, and PhD students. Table 1 shows the numbers of students in BIM courses at the university.

Table 1: Number of students in BIM courses at the Technical University of Denmark between 2011 and 2015,¹ estimated numbers of students in 11913 and 11933 that have been replaced by 11951, 11952 and 11035.

Number and name on course	11951: BIM and visual communication	11952: Building Information Modelling	11035: Advanced BIM for architectural engineering	11000: Engineering work	11990: Engineering work	11031: Building Information Modeling	11034: Advanced Building Information Modeling	11080: Advanced Building Design	11626 Process and Data Modeling for the Built Environment.
Type	BEng.	BEng.	BEng.	BSc.	BSc.	MSc.	MSc.	MSc.	PhD.
ECTS	5	5	5	10	10	5	5	10	5
Language	Danish	Danish	Danish	Danish	Danish	Danish	English	English	English
2011	45 ¹	45 ¹	21	58	60	59	85	77	–
2012	45 ¹	45 ¹	7	59	60	71	101	48	–
2013	45 ¹	45 ¹	30	64	56	88	107	56	–
2014	58	59	17	62	57	98	108	74	4
2015	61	58	51	66	56	74	107	108	7

3.1 BEng Building Design

The BEng Building Design students are offered an introductory course 11951 *BIM and visual communication* that primarily is focusing on modelling in Revit [5], producing and annotating drawing in AutoCAD and, finally, sketching is introduced. Students continue in 11952 *Building Information Modeling* that has elements of Revit in the course, but also includes use of classification, ICT contract, Level of Development (LoD), and an introduction to IFC and use of IFC files in Solibri Model Checker [6]. By investigating the IFC files in Solibri Model Checker, students are becoming familiar with which objects and properties are transferred while using IFC, and how the export can be configured. Students are also introduced to BIM Collaboration Format (BCF), and have to generate BCF files in Solibri Model Checker and view the BCF in another tool e.g. the viewer from Data Design System in Norway.

11035 *Advanced BIM for architectural engineering* is the third BIM course for architectural engineering students. This course is mainly focusing visual programming in Grasshopper [7], which is a plugin to Rhino, and testing the facilities in DTU Skylab for digital fabrication.

3.2 BSc Architectural Engineering and Building Technology students

Courses 11000 *Engineer work* and 11990 *Engineering Work for Architectural Engineering* students include learning objectives in CAD and BIM. Students are taught in BIM generally and mainly use Revit and AutoCAD in the course. Course 11031 is similar to 11952 for BEng Architectural Engineering students and focuses on the BIM concept and enabling students to use BIM tools while solving design tasks within a model-based working method. Like 11952, 11031 has exercises in Revit, but also includes use of classification, ICT contract, requirements of the Danish ICT Regulations, LoD, and an introduction to IFC and using IFC files in Solibri Model Checker. Finally a report on a topical issue related to the course content is handed over. The topic is often related to standardization and open BIM.

3.3 MSc Architectural Engineering and Building Technology students

Most students participate in 11034 *Advanced BIM*, including BEng students who are adding a Master degree on top on their bachelor of engineering education. 11034 *Advanced BIM* includes visual programming in Dynamo [8] and demonstrating use of BIM, and integration between building models and technical analysis in numerous areas like structural engineering, space management, and cost estimation. The course also contains a lecture on BIM-based working methods, including Information Delivery Manuals [4], Penn State BIM Execution Planning Guide [9] and COBIM guides from Finland [10]. The COBIM guidelines are developed for most disciplines and are promoting open BIM by specifying use of the IFC format. The Danish ‘3D working methods’ [11] developed in the Digital Construction project, which matched the requirement on exchanging data in IFC format, was released in 2006, but the latest version of the guides is only available in Danish. Bips is only using the BIM concept if all information on a facility or project are fully integrated, and it has therefore been decided not to use the BIM concept so far. In 2015 the BIM server from Netherland was included in the course in order to demonstrate use of BIMQL [12], which is a BIM query language that has similarities with SQL [13] for relational databases. Through exercises, the students became familiar with the ability to extract information from the BIM server in IFC format. The model server is based on importing information in IFC format that can be generated by any IFC-compatible tool.

The exercise on model checking was done by using Solibri Model Checker like in course 11031 *Building Information Modeling*, but in the advanced course the students shall combine and configure rulesets. The students are not only becoming familiar with Solibri Model Checker, but also have to become familiar with the data structure in IFC, and how IFC are implemented in software tools.

A big number of students are including 11080 *Advanced Building Design* as a part of their education. Students are here designing a 20–40-storey building during the course. The students have to submit BIM models of the building in IFC format as a mandatory delivery. A paper specifically on the course has been published on the course [14].

3.4 PhD students

DTU is offering a PhD course in open BIM, 11626 *Process and Data Modeling for the Built Environment*. The course is offered annually as a regular course or as a course in conjunction with international conferences. The course is based on methods developed by buildingSMART. A detailed description of the course is specified in a paper [15].

4. Contribution in open BIM from education

4.1 Special courses

There is the opportunity for students next to the regular courses to conduct specialized courses, and most students taking special courses in relation to open BIM are using the concept to solve an engineering problem.

A sample of special courses in relation to open BIM includes:

- Use of BCF for coordination of issues [16]
- IDM for daylight design [17]
- IDM for HVAC concepts and HVAC demands [18]

4.2 Bachelor projects

Some students have used open BIM in their bachelor project. Below is listed samples of such projects:

- Verifying accessibility by rule-based testing in Solibri Model Checker based on analysing IFC models [19].
- Required properties for cost estimating of concrete structures [20].

4.3 Master theses

A number of students have made master thesis on open BIM or used open BIM methodologies.

- Structural calculation based on inputting and exporting information in IFC format [21].
- IDM for energy analysis. Development of a translator for importing IFC data to energy analysis [22].
- Testing importing and exporting structural information through IFC [23].
- IDM of the structural process according to the standard services agreement specified by the professional association, and a proposed revised BIM-based process [24].

- Exchange requirement for indoor climate analysis, and mapping to IFC specifications [25].
- IDM for lighting design [26].
- Testing COBie for delivering of data for operation and maintenance of curtain walls [27]
- Use of BCF as a general method to store changes, change requests, exchange of information and monitor progress [28].
- IDM for BIM-based design of building services components and developing a tool for adding IFC properties [29].
- IFC-based fire safety assessment tool [30].
- Rule-based checking of level of development in open format [31].

4.4 PhD projects

PhD projects at DTU using open BIM:

- Methods for Implementing Information and Communication Technology in Sustainable Building Processes by Thomas Fænø Mondrup.
- Digitalisation as a driver for standardisation of specification and design of buildings by Niels Treldal.
- Digital infrastructure and Building Information Models in the design and planning of building services by Mads Holten Rasmussen.
- A framework for Information Delivery Manuals [32].

5 Experiences

The findings from the ordinary courses including open BIM components are that the students see this as an abstract element in the course, and would prefer more training in specific BIM tools instead. Many students are not expecting issues regarding interoperability, and assume that information can flow freely between applications. It is based mainly in the students lack of knowledge of the construction industry's actual status and an idealized view of all processes proceed rationally and optimized. As students become aware of the problems, they are surprised that the industry has accepted the situation, where information has to be manipulated manually or re-entered in order to be used in other applications.

Some students have unrealistic expectations as to how open BIM can be used. This can be for several reasons, like lack of understanding between the full specification of IFC and the implemented sub sets of the specification. Another aspect of this is the lack of robustness in implementation or certification of software products. A different aspect that is outside students' minds is companies' business reasons for supporting or not supporting easy and seamless transfer of information between applications from different vendors.

It is also experienced that the advantage of open BIM that enables sharing or exchange of information between any compatible application also makes the transfer fragile, since the ambiguity in the way that the information is handled by different applications is made immediately visible when the information is imported in another tool. There is a risk of failure since there are endless combinations of different releases of software products from different vendors that can exchange information according to different versions of the specifications,

whereas direct translators or plugins dedicated for specific purposes and releases of specific applications are more robust.

Based on the number of students taking special courses, bachelor projects and master theses there is an interest among students to investigate the possibilities to use and further develop the open BIM concept. It can be ascertained that the interest is growing through the education alongside the construction industry's actual problems are recognized.

Students are looking for more training material on open BIM, and they find the data definition language Express [33] incompatible with the software tools they are familiar with. IFC is defined in Express. The structure of IFC is also seen as complex, but is not a barrier for committed students who are willing to make a big effort to understand the concept behind IFC.

Students developing Information Delivery Manuals (IDM) according to [4] are finding it difficult to register existing process flows and exchange requirements, and to specify future process flows and exchange requirements. One of the main difficulties in registering existing process flows and exchange requirements is that there is generally no consensus in the industry about detailed procedures in how to perform a project, and the exchange requirements seem to be defined by individuals project by project. Another observation is that the existing process flow and exchange requirements are based on human-assisted workflows and information exchanges, and therefore are not prepared for a seamless BIM-based working method.

Many of the projects are done in collaboration with the industry, which often is willing to assist the students and give access to data from construction projects. Students have applied the open BIM concept in a variety of different engineering disciplines that are comparable with the engineering areas they are taught at DTU at the Department of Civil Engineering. However, domains outside the department, like acoustics, electrics, road, rail, and facility engineering, which are taught at different departments, have so far been outside the scope of open BIM among engineering students at DTU.

Through their project, students are able to identify if they are able to map their specific requirements to IFC, for example, or if they should propose extensions to the specifications.

Table 2: A competence matrix describing the courses defined competence levels set in the context of the successive progression throughout the total course agenda.

Levels of knowledge	Level 1			Level 2			Level 3			Level 4		
Course numbers	11951	11000	11990	11052	11031	11035	11034	11080	11626	Special courses	Master theses	PhD studies
Assessment												
Analyses												
Application												
Understanding												
Knowledge												

6 Conclusion

Civil Engineering and Architectural Engineering students at DTU are taught in open BIM in several courses. It is pursued in the development of course out of the tender, to enable students to acquire knowledge, also in the field of open BIM, in a growing competence level from pure knowledge about open BIM to professional analysis, use and assessment. Most students will be introduced to the open BIM concept, and students who are participating in advanced BIM or building design courses have to become familiar with or deliver information in IFC format.

A number of students have explored the capabilities of IFC and BCF, and suggested extensions when needed. Students have experienced difficulties in documenting existing workflow in IDM, since most processes and exchange requirements are not standardised in the industry and not even documented.

At the university the open BIM concept is driven by a limited number of people and not generally accepted as the preferred way of handling exchange of information between applications.

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